Coronary Vessel Quantification for Interventional Device Sizing using Inverse Geometry X-ray Fluoroscopy

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Proper interventional device selection is critical for effective treatment of lesions in coronary arteries. Ideally, the device (angioplasty balloon, stent, etc.) should be as long as the coronary stenosis, and when deployed, the diameter should match that of nearby healthy artery segments. Quantitative coronary angiography (QCA) can be used to support device size selection, but the accuracy of measurements using conventional x-ray fluoroscopy depends on proper calibration of vessel magnification with a reference object and avoiding vessel foreshortening. Scanning Beam Digital X-ray (SBDX) is a low-dose inverse geometry x-ray fluoroscopy system that produces multiple tomosynthetic images at 15-30 frames/sec instead of conventional 2D projections. It is hypothesized that by using the out-of-plane blurring property of tomosynthesis imaging, the coronary vessels can be localized in 3D in a single frame period. This information can then be used to directly measure the vessel diameter and true vessel length, without calibration and when the vessel appears foreshortened.

This dissertation describes the design and validation of a vessel sizing algorithm based on this principle. An initial implementation demonstrated the feasibility of calibration-free vessel sizing in phantoms over a range of magnifications and degrees of foreshortening. The algorithm was redesigned to improve robustness under sub-optimal imaging conditions. Further validation was performed in phantoms using a range of vessel magnifications, degrees of foreshortening, and levels of image quality. For vessel phantoms with a peak signal difference to noise ratio between 2 and 10 at an angle $\leq 45°$ relative to the image plane, the length error (mean ± 1 SD) was 0.01 ± 1.12 mm and the diameter error was 0.02 ± 0.08 mm. The algorithm was validated in vivo by comparing results to "gold standard" measurements (intravascular ultrasound for diameter, CT angiography for segment length). Using a healthy porcine model, vessel measurement errors were -0.49 ± 1.76 mm for length and 0.07 ± 0.27 mm for diameter. Results in phantoms and in vivo demonstrate this technique can accurately determine vessel lengths and diameters in a range of clinically relevant conditions, without the limitations of conventional methods, which require magnification calibration and the avoidance of foreshortening.